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Appendix F

Thermal Plume Technical Report

Prepared for
Vantage Data Centers
Santa Clara, California

Prepared by
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Project Number
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Date
December, 2017

PLUME ASSESSMENT

MCLAREN DATA CENTER

SANTA CLARA, CALIFORNIA

RAMBOLL ENVIRON

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ACRONYMS AND ABBREVIATIONS

ACFM	Actual cubic feet per minute
CASA	Civil Aviation Safety Authority
CEC	California Energy Commission
F	Fahrenheit
ft	feet
ft/s	feet per second
K	Kelvin
m	meter
m/s	meters per second
s	second

1. INTRODUCTION

1.1 Background

Vantage Data Centers has proposed to develop a data center in Santa Clara, California, in a location near the San Jose airport. The data center will involve forty eight (48) backup emergency diesel generators and seventy two (72) roof-mounted air chillers.

The California Energy Commission (CEC) has required Vantage Data Centers to evaluate the potential implications of the thermal plumes from the proposed stacks on aviation safety. Ramboll Environ has been engaged by Vantage to undertake this assessment and has completed a screening assessment. The assessment of vertical plume velocity was conducted in accordance with CEC methodology, invoking the Spillane methodology to analytically solve for plume height. The effect of merged plumes are taken into account.

The acceptable plume vertical velocity threshold is specified in recent supplemental testimony of James Adams and Appendix TT-2 of a CEC project titled “Palmdale Energy Project” (PEP) docketed on December 29, 2016. This project defines the significance level of 5.3 m/s at all heights above 1,500 feet AGL (above ground level). The threshold of 5.3 m/s average velocity is used in this assessment.

The vertical velocity of the emissions from the emergency standby generators and the air-cooled chillers will be greater than 5.3 m/s at the point of discharge and therefore an assessment of the vertical velocity is required to be undertaken.

2. SCREENING ASSESSMENT

2.1 Vertical plume velocity guidelines

The assessment will conservatively determine the potential for turbulence generated by the plume-averaged vertical velocity of the emergency standby generator and chiller exhaust plumes. The method uses worst-case assumptions of calm winds and neutral atmospheric conditions for the entire vertical extent of the plume to determine the worst-case impacts.

Since the development of a simple-cycle gas turbine power station at the end of a runway in Australia in the mid-1990s,[1] the Australian Civil Aviation Safety Authority (CASA) has taken an active role in the review of the siting of facilities with the potential to affect aviation activities.

Potential hazards that could affect the safety of aircraft include tall visible or invisible obstructions. Visible obstructions include structures such as tall stacks or communication towers. Invisible obstructions include industrial exhausts that generate significant turbulence due to high velocity and buoyancy. CASA has issued an Advisory Circular, (CASA 2004) that specifies the requirements and methodologies to be used to assess whether a new industrial plume is likely to have adverse implications for aviation safety.

The general CASA requirement is to determine the height at which the plume (or plumes) could generate atmospheric turbulence and to determine the dimensions of the plume in these circumstances. The frequency of in-plume vertical velocities at the lowest height an aircraft may travel over the site, and at other heights are also required. For large plumes that are remote from airports, CASA requires an assessment that determines the size of a hazard zone to alert pilots to the potential hazard. Normally this analysis uses a sophisticated air dispersion model that determines plume vertical velocities and lateral/vertical extents based on wind fields generated from actual meteorological data. Rather than use such a refined technique, a conservative screening analysis based on calm wind field assumptions was used for this project.

For this assessment, the plume-averaged vertical velocities were calculated as a function of height under calm conditions. The established CEC significance criteria is for an averaged plume velocity to equal or exceed 5.3 m/s at altitudes where aircraft can operate. This significance criteria was adopted in the CEC Palmdale Energy Project.

[1] Note that this project consists of internal combustion engines (ICEs) and air-cooled chillers that have plume exhausts with much smaller volumetric flows and buoyancy fluxes than the turbine projects that elicited the initial interest of CASA.

3. MODEL INPUT DATA

3.1 Emissions information

The proposed data center will have a number of atmospheric emission sources including:

1. Emergency standby diesel generators; and
2. Air-cooled “free cooling” chillers;

The highest exit velocity and emissions volume is associated with the emergency generators and therefore the screening assessment has primarily focused on these sources. An additional scenario associated with the cooling towers was also included. The emission parameters used within the screening assessment for the three scenarios considered for emergency generators and one scenario considered for the chillers are presented in Table 1.

Table 1. Stack Parameters

	Emergency generators		
	Scenario 1 - Worst-case	**Scenario 2**	**Scenario 3**
Ambient Potential Temp (F)	30	59	76
Stack Height (feet)	45.2	45.2	45.2
Stack Diameter (feet)	1.7	1.7	1.7
Stack Velocity at exit (m/s)	59.2	59.2	59.2
Stack Potential Temp (F)	891.9	891.9	891.9
	Air-cooled chillers		
	Scenario 1 - Worst-case		
Ambient Potential Temp (F)	30		
Stack Height (feet)	120		
Stack Diameter (feet)	2.3		
Stack Velocity at exit (m/s)	9.4		
Stack Potential Temp (F)	101.5		

The 48 generator stacks and 72 chiller stacks are arranged in the configuration displayed in Figure 1. Although the project consists of 47 3-MW generators and one 500-kW generator, the 500-kW generator was conservatively assumed to have the same stack parameters as a 3-MW generator for ease of calculation. The chillers are located on the roofs of the buildings. Buildings are approximately 106 feet in height. The chiller is placed on a dunnage platform on the roof and the height of the chiller is 8 feet from the top of the dunnage platform. The top of the chiller would be 120 feet above ground level (including the 5’ for the dunnage platform), so that was the height assumed for the chiller stack height.

3.2 Methodology

This assessment analyses vertical plume rise using the Spillane methodology, developed by Dr. Kevin Spillane, to analytically solve for plume heights above the jet phase in calm conditions. Three methods were evaluated: Method 1 assumes conservation of buoyancy and a Gaussian distribution of the vertical velocities, Method 2 is based on the Best et al., 2003 paper's analytical solution, and Method 3 considers the enhancement of vertical velocities that may occur if the plumes from multiple stacks merge and form a higher buoyancy combined/merged plume. Method 3, developed by the CEC, is based on the single stack plume velocity multiplied by the number of stacks raised to the 0.25 power.

Table 2. Model Results

Assumptions							Maximum Height Above Ground with Vertical Velocity above Threshold (5.3 m/s)		
Source (Number of Units)	**Ambient Temperature**	**Stack Height (h_s)**	**Stack Diameter (D)**	**Stack Velocity (V_{exit})**	**Volumetric Flow**	**Stack Potential Temperature (θ_S)**	**Method 1**	**Method 2**	**Merged Plumes**
Emergency Diesel Generators (48)	272 K (30°F)	13.77 m (45.2 ft)	0.51 m (1.7 ft)	59.22 m/s (194.3 ft/s)	25,620 ACFM	751 K (891.9°F)	32.92 m (108 ft)	27.74 m (91 ft)	27.74 m (91 ft)
Chillers (72)	272 K (30°F)	36.58 m (120 ft)	0.71 m (2.3 ft)	9.40 m/s (30.8 ft/s)	8,476 ACFM	312 K (101.5°F)	40.84 m (134 ft)	40.54 m (133 ft)	42.37 m (139 ft)

4. MODEL RESULTS

4.1 Worst-case calm wind scenario

Plumes that may have a vertical velocity of greater than 5.3 m/s are of primary interest to the airport safety authorities. While the vertical velocity of the plumes at the point of discharge are in excess of 5.3 m/s, the vertical velocity is quickly dissipated following discharge as the plume mixes with ambient air.

An assessment assuming calm winds for the entire height of the plume and an ambient temperature of 30 F is presented here to represent the worst-case. Results of the plume vertical velocities at various heights are presented in Appendix A and summarized in Table 2 based both the Spillane methodology and the CEC methodology (merged plumes).

For this conservative analysis, both single plume and merged plume velocities were evaluated. Using the Spillane methodology Method 1, the plume-averaged vertical velocity drops below the CEC screening threshold of 5.3 m/s at 108 feet above ground level for one emergency generator and at 134 feet above ground level for one chiller. Method 2 yielded slightly lower heights than Method 1. Using the CEC methodology of merged plumes, the vertical velocity drops below 5.3 m/s for the 48 generators at 91 feet above ground level and for the 72 chillers at 139 feet above ground level.

5. SUMMARY AND CONCLUSION

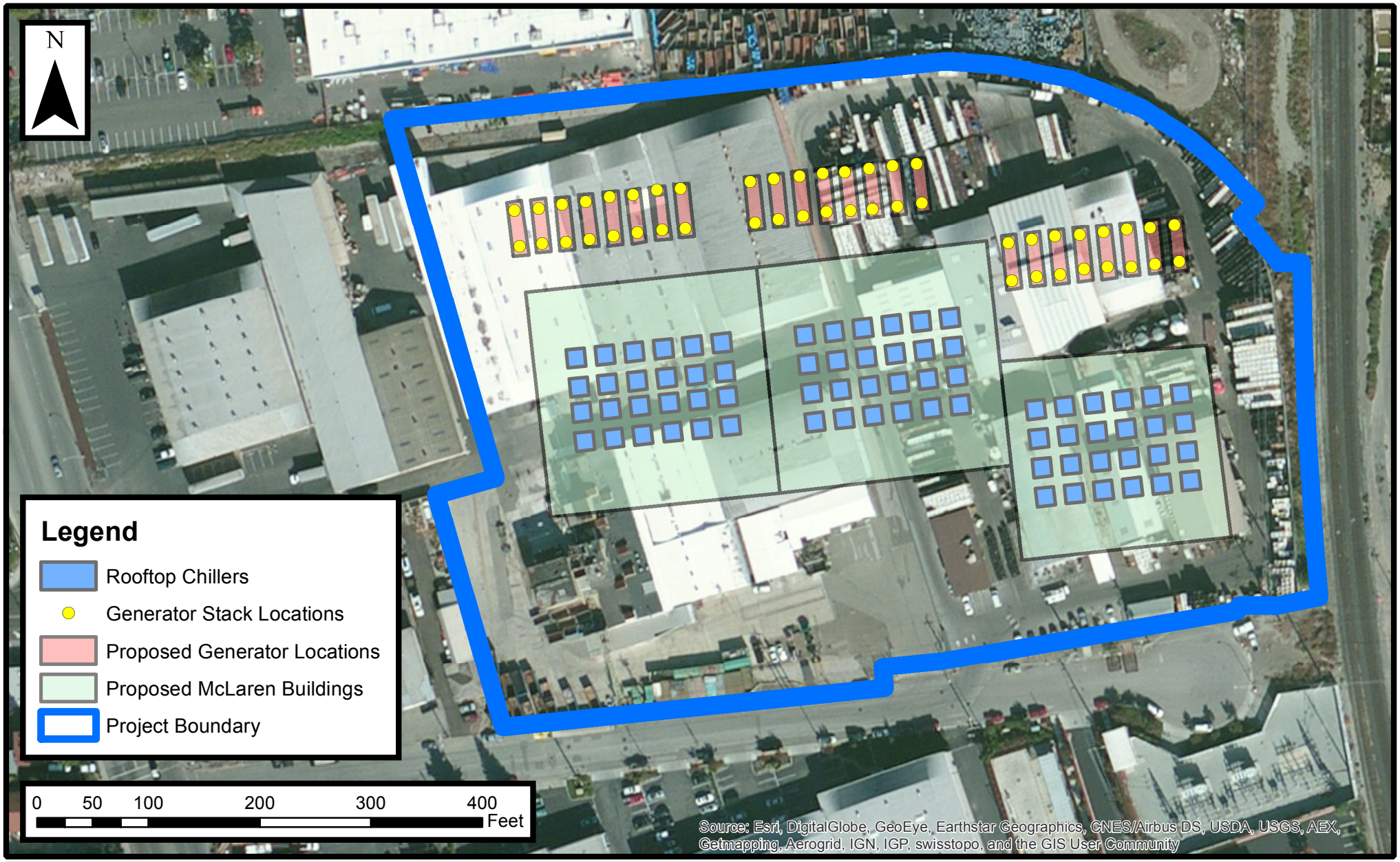
Modelling of the characteristics of the plumes from the diesel emergency generators and roof-mounted air chillers at the Vantage McLaren data center has been completed and indicates:

1. Under worst-case ambient conditions and calculation methodology, predicted vertical velocities are below 5.3 m/s for emergency generators at a height of 108 feet above ground; and
2. Under worst-case ambient conditions and calculation methodology, predicted vertical velocities are below 5.3 m/s for roof-mounted air chillers at a height of 139 feet above ground.

6. REFERENCES

Best, P., Jackson, L., Killip, C., Kanowski, M., Spillane, K. (2003) “Aviation Safety and Buoyant Plumes.” Clean Air Conference, Newcastle, New South Wale, Australia.

FIGURES



RAMBOLL ENVIRON

DRAFTED BY: | DATE:

Stack Locations
McLaren Project
Vantage Data Centers
Santa Clara, California

FIGURE
1
PROJECT

	Assumptions						Maximum Height Above Ground with Vertical Velocity above Threshold (5.3 m/s)		
Source (Number of Units)	**Ambient Temperature**	**Stack Height (h_s)**	**Stack Diameter (D)**	**Stack Velocity (V_{exit})**	**Volumetric Flow**	**Stack Potential Temperature (θ_s)**	**Method 1**	**Method 2**	**Merged Plumes**
Emergencey Diesel Generators (48)	272 K (30°F)	13.77 m (45.2 ft)	0.51 m (1.7 ft)	59.22 m/s (194.27 ft/s)	25,620 ACFM	751 K (891.9°F)	32.92 m (108 ft)	27.74 m (91 ft)	27.74 m (91 ft)
Chillers (72)	272 K (30°F)	15.24 m (50.0 ft)	0.71 m (2.3 ft)	9.40 m/s (30.8 ft/s)	8,476 ACFM	312 K (101.5°F)	40.84 m (134 ft)	40.54 m (133 ft)	42.37 m (139 ft)

Stack Parameters			
Emergency generators			
	Scenario 1 - Worst-case	Scenario 2	Scenario 3
Ambient Potential Temp (F)	30	59	76
Stack Height (feet)	45.17	45.17	45.17
Stack Diameter (feet)	1.7	1.7	1.7
Stack Velocity at exit (m/s)	59.22922	59.22922	59.22922
Stack Potential Temp (F)	891.9	891.9	891.9
Air-cooled chillers			
	Scenario 1 - Worst-case		
Ambient Potential Temp (F)	30		
Stack Height (feet)	120		
Stack Diameter (feet)	2.3		
Stack Velocity at exit (m/s)	9.4		
Stack Potential Temp (F)	101.5		

PETER BEST PAPER ILLUSTRATIVE EXAMPLE - SINGLE TURBINE - Assumes Heights in Table 2 are meters above ground

Plume Averaged Vertical Velocities: **"*Aviation Safety and Buoyant Plumes*," Peter Best, et. al.**

Ambient Conditions:					Constants:		
Ambient Potential Temp θ_a	272	Kelvins	30	°F	Assume neutral conditions (dθ/dz=0)		
Plume Exit Conditions:					Gravity g	9.81	m/s^2
Stack Height h_s	13.77	meters	45.2	feet	λ	1.11	
Stack Diameter D	0.51	meters	1.7	feet		0.3048	meters/feet
Stack Velocity V_{exit}	59.22	m/s	194.3	ft/sec			
Volumetric Flow	12	cu.m/sec	25,427	ACFM	$\pi V_{exit}D^2/4$		Sect.2/¶1
Stack Potential Temp θ_s	751	Kelvins	891.9	°F	Back-Calc'd from Buoyancy Flux		
Initial Stack Buoyancy Flux F_o	24	m^4/s^3			$gV_{exit}D^2(1-\theta_a/\theta_s)/4$ = Vol.Flow(g/π)(1-θ_a/θ_s)		Sect.2/¶1
Plume Buoyancy Flux F	N/A	m^4/s^3			$\lambda^2 gVa^2(1-\theta_a/\theta_p)$ for a,V,θ_p at plume height (not used here)		

Conditions at End (Top) of Jet Phase:

Height above Stack z	3.188	meters*	10.5	feet*	6.25D, meters*=meters above stack top		Sect.3/¶1
Height above Ground z+h_s	16.956	meters	55.6	feet	h_s + 6.25D		"
Vertical Velocity V_{plume}	29.610	m/s	97.15	ft/sec	$0.5V_{exit}$	$V_{exit}/2$	"
Plume Top-Hat Diameter 2a	1.020	meters	3.3	feet	2D	Conservation of momentum	"

Spillane Methodology - Analytical Solutions for Calm Conditions for Plume Heights above Jet Phase

Plume Top-Hat Radius a	**Solutions in Table Below**				0.16(z-z_v), or linear increase with height	Sect.2/Eq.6
Virtual Source Height z_v	1.269	meters*	4.2	feet*	$6.25D[1-(\theta_e/\theta_s)^{1/2}]$, meters*=meters above stack top	Sect.2/Eq.6
Height above Ground z_v+h_s	15.037	meters	49.3	feet	where $(\theta_e/\theta_s)^{1/2} = (\theta_e/\theta_s)^{1/2}$= 0.601911273	

Method(1): Simplified Plume-averaged Vertical Velocity V' - Assumes Product Va constant above jet phase such that $V_{plume}(2a) = V_{exit}D$

Vertical Velocity V'	**Solutions in Table Below**				$V_{exit}D/2a'$ (conservation of buoyancy)	Sect.3&4

Method(2): Plume-averaged Vertical Velocity V given by Analytical Solution in Paper where Product Va given by equations below:

Vertical Velocity V	**Solutions in Table Below**				$\{(Va)_o^3 + 0.12F_o [(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)}$ / a	Sect.2.1(6)
Product $(Va)_o$	9.090	m^2/s			$V_{exit}D/2(\theta_e/\theta_s)^{1/2}$	

Table of plume Top-Hat Diameters (2a) and Plume-averaged Vertical Velocities for both Method(1) (assuming conservation of buoyancy & gaussian distribution of vertical velocities) and Method (2) (based on Peter Best's paper's Analytical Solution) starting at end of jet phase:

from 100 meters above ground in increments of 50.0 meters

					Vert.Vel (m/s)	
					Method(1)	Method(2)
	Ht above Ground =	h_{plume}+h_s	D_{plume}=2a=		V_{plume}=	$\{(Va)_o^3$+0.12F_o[$(z-z_v)^2$
Height above stack top, meters*	meters	feet	2*0.16(z-z_v)		V_{exit}*D/2a	-$(6.25D-z_v)^2$]$\}^{1/3}$ / a
End of jet phase at 6.25D = 3.188 meters*	***16.956***	***55.6***	***1.020***			***29.61***
86.232 meters*	**100.000**	328.1	27.188		1.11	**2.05**
136.232 meters*	150.000	492.1	43.188		0.70	1.74
186.232 meters*	**200.000**	656.2	59.188		0.51	**1.57**
236.232 meters*	250.000	820.2	75.188		0.40	1.45
286.232 meters*	**300.000**	984.3	91.188		0.33	**1.35**
336.232 meters*	350.000	1148.3	107.188		0.28	1.28

386.232 meters*	400.000	1312.3	123.188	0.25	1.22
436.232 meters*	450.000	1476.4	139.188	0.22	1.18
486.232 meters*	**500.000**	1640.4	155.188	0.19	**1.13**
536.232 meters*	550.000	1804.5	171.188	0.18	1.10
586.232 meters*	600.000	1968.5	187.188	0.16	1.06
636.232 meters*	650.000	2132.5	203.188	0.15	1.04
686.232 meters*	**700.000**	2296.6	219.188	0.14	**1.01**
736.232 meters*	750.000	2460.6	235.188	0.13	0.99
786.232 meters*	800.000	2624.7	251.188	0.12	0.97
836.232 meters*	850.000	2788.7	267.188	0.11	0.95
886.232 meters*	900.000	2952.8	283.188	0.11	0.93
936.232 meters*	950.000	3116.8	299.188	0.10	0.91
986.232 meters*	**1000.000**	3280.8	315.188	0.10	**0.89**
1036.232 meters*	1050.000	3444.9	331.188	0.09	0.88
1086.232 meters*	1100.000	3608.9	347.188	0.09	0.87
1136.232 meters*	1150.000	3773.0	363.188	0.08	0.85
1186.232 meters*	1200.000	3937.0	379.188	0.08	0.84
1236.232 meters*	1250.000	4101.0	395.188	0.08	0.83

4.520 meters*	18.288	60.0	1.040	29.03	17.63
7.568 meters*	21.336	70.0	2.016	14.98	9.42
7.873 meters*	21.641	71.0	2.113	14.29	9.02
8.178 meters*	21.946	72.0	2.211	13.66	8.66
8.483 meters*	22.251	73.0	2.308	13.08	8.34
8.787 meters*	22.555	74.0	2.406	12.55	8.04
9.092 meters*	22.860	75.0	2.503	12.06	7.76
9.397 meters*	23.165	76.0	2.601	11.61	7.51
9.702 meters*	23.470	77.0	2.699	11.19	7.28
10.007 meters*	23.775	78.0	2.796	10.80	7.06
10.312 meters*	24.079	79.0	2.894	10.44	6.86
10.616 meters*	24.384	80.0	2.991	10.10	6.67
10.921 meters*	24.689	81.0	3.089	9.78	6.50
11.226 meters*	24.994	82.0	3.186	9.48	6.33
11.531 meters*	25.299	83.0	3.284	9.20	6.18
11.836 meters*	25.604	84.0	3.381	8.93	6.04
12.140 meters*	25.908	85.0	3.479	8.68	5.90
12.445 meters*	26.213	86.0	3.576	8.44	5.78
12.750 meters*	26.518	87.0	3.674	8.22	5.66
13.055 meters*	26.823	88.0	3.771	8.01	5.54
13.360 meters*	27.128	89.0	3.869	7.81	5.44
13.664 meters*	27.432	90.0	3.967	7.61	5.34
13.969 meters*	27.737	91.0	4.064	7.43	5.24
14.274 meters*	28.042	92.0	4.162	7.26	5.15
14.579 meters*	28.347	93.0	4.259	7.09	5.06
14.884 meters*	28.652	94.0	4.357	6.93	4.98
15.188 meters*	28.956	95.0	4.454	6.78	4.90
15.493 meters*	29.261	96.0	4.552	6.64	4.83
15.798 meters*	29.566	97.0	4.649	6.50	4.76
16.103 meters*	29.871	98.0	4.747	6.36	4.69
16.408 meters*	30.176	99.0	4.844	6.23	4.62
16.712 meters*	30.480	100.0	4.942	6.11	4.56
17.017 meters*	30.785	101.0	5.039	5.99	4.50
17.322 meters*	31.090	102.0	5.137	5.88	4.44
17.627 meters*	31.395	103.0	5.235	5.77	4.39
17.932 meters*	31.700	104.0	5.332	5.66	4.33
18.236 meters*	32.004	105.0	5.430	5.56	4.28
18.541 meters*	32.309	106.0	5.527	5.46	4.23
18.846 meters*	32.614	107.0	5.625	5.37	4.19
19.151 meters*	32.919	108.0	5.722	5.28	4.14
19.456 meters*	33.224	109.0	5.820	5.19	4.10
19.760 meters*	33.528	110.0	5.917	5.10	4.06
22.808 meters*	36.576	120.0	6.893	4.38	3.70

Stack Distances (ft)	Number of Stacks
21	48

ft	m/s	merged cells	Plume Diamter Feet
60	17.63	1.00	3.41
70	9.42	1.00	6.61
71	9.02	1.00	6.93
72	8.66	1.00	7.25
73	8.34	1.00	7.57
74	8.04	1.00	7.89
75	7.76	1.00	8.21
76	7.51	1.00	8.53
77	7.28	1.00	8.85
78	7.06	1.00	9.17
79	6.86	1.00	9.49
80	6.67	1.00	9.81
81	6.50	1.00	10.13
82	6.33	1.00	10.45
83	6.18	1.00	10.77
84	6.04	1.00	11.09
85	5.90	1.00	11.41
86	5.78	1.00	11.73
87	5.66	1.00	12.05
88	5.54	1.00	12.37
89	5.44	1.00	12.69
90	5.34	1.00	13.01
91	5.24	1.00	13.33
92	5.15	1.00	13.65
93	5.06	1.00	13.97
94	4.98	1.00	14.29
95	4.90	1.00	14.61
96	4.83	1.00	14.93
97	4.76	1.00	15.25
98	4.69	1.00	15.57
99	4.62	1.00	15.89
100	4.56	1.00	16.21
101	4.50	1.00	16.53
102	4.44	1.00	16.85
103	4.39	1.00	17.17
104	4.33	1.00	17.49
105	4.28	1.00	17.81
106	4.23	1.00	18.13
107	4.19	1.00	18.45
108	4.14	1.00	18.77
109	4.10	1.00	19.09
110	4.06	1.00	19.41
120	3.84	1.16	22.61

23.113 meters*	36.881	121.0	6.990	4.32	3.68
23.418 meters*	37.186	122.0	7.088	4.26	3.65
23.723 meters*	37.491	123.0	7.185	4.20	3.62
24.028 meters*	37.796	124.0	7.283	4.15	3.59
24.332 meters*	38.100	125.0	7.380	4.09	3.57
24.637 meters*	38.405	126.0	7.478	4.04	3.54
24.942 meters*	38.710	127.0	7.575	3.99	3.52
25.247 meters*	39.015	128.0	7.673	3.94	3.49
25.552 meters*	39.320	129.0	7.770	3.89	3.47
25.856 meters*	39.624	130.0	7.868	3.84	3.44
28.905 meters*	42.673	140.0	8.843	3.42	3.24
31.953 meters*	45.721	150.0	9.819	3.08	3.08
35.001 meters*	48.769	160.0	10.794	2.80	2.95
38.049 meters*	51.817	170.0	11.770	2.57	2.84
41.097 meters*	54.865	180.0	12.745	2.37	2.74
44.145 meters*	57.913	190.0	13.720	2.20	2.66
47.193 meters*	60.961	200.0	14.696	2.06	2.58
77.673 meters*	91.441	300.0	24.449	1.24	2.13
108.153 meters*	121.921	400.0	34.203	0.88	1.89
138.634 meters*	152.402	500.0	43.957	0.69	1.73
169.114 meters*	182.882	600.0	53.711	0.56	1.62
199.595 meters*	213.363	700.0	63.464	0.48	1.53
230.075 meters*	243.843	800.0	73.218	0.41	1.46
260.555 meters*	274.323	900.0	82.972	0.36	1.40
291.036 meters*	304.804	1000.0	92.725	0.33	1.35
321.516 meters*	335.284	1100.0	102.479	0.29	1.30
351.996 meters*	365.764	1200.0	112.233	0.27	1.26
382.477 meters*	396.245	1300.0	121.987	0.25	1.23
412.957 meters*	426.725	1400.0	131.740	0.23	1.20
443.438 meters*	457.206	1500.0	141.494	0.21	1.17
473.918 meters*	487.686	1600.0	151.248	0.20	1.14
504.398 meters*	518.166	1700.0	161.001	0.19	1.12
534.879 meters*	548.647	1800.0	170.755	0.18	1.10
565.359 meters*	579.127	1900.0	180.509	0.17	1.08
595.839 meters*	609.607	2000.0	190.263	0.16	1.06
626.320 meters*	640.088	2100.0	200.016	0.15	1.04
656.800 meters*	670.568	2200.0	209.770	0.14	1.03
687.281 meters*	701.049	2300.0	219.524	0.14	1.01
717.761 meters*	731.529	2400.0	229.277	0.13	1.00
748.241 meters*	762.009	2500.0	239.031	0.13	0.98
778.722 meters*	792.490	2600.0	248.785	0.12	0.97
809.202 meters*	822.970	2700.0	258.539	0.12	0.96
839.682 meters*	853.450	2800.0	268.292	0.11	0.94
870.163 meters*	883.931	2900.0	278.046	0.11	0.93
900.643 meters*	914.411	3000.0	287.800	0.10	0.92
931.124 meters*	944.891	3100.0	297.553	0.10	0.91
961.604 meters*	975.372	3200.0	307.307	0.10	0.90
992.084 meters*	1005.852	3300.0	317.061	0.10	0.89
1022.565 meters*	1036.333	3400.0	326.815	0.09	0.88
1053.045 meters*	1066.813	3500.0	336.568	0.09	0.88
1083.525 meters*	1097.293	3600.0	346.322	0.09	0.87
1114.006 meters*	1127.774	3700.0	356.076	0.08	0.86
1144.486 meters*	1158.254	3800.0	365.829	0.08	0.85
1174.966 meters*	1188.734	3900.0	375.583	0.08	0.84
1205.447 meters*	1219.215	4000.0	385.337	0.08	0.84

121	3.82	1.17	22.93
122	3.81	1.19	23.25
123	3.79	1.20	23.57
124	3.77	1.22	23.89
125	3.76	1.23	24.21
126	3.74	1.25	24.53
127	3.73	1.26	24.85
128	3.71	1.28	25.17
129	3.70	1.29	25.49
130	3.68	1.31	25.81
140	3.57	1.46	29.01
150	3.47	1.61	32.21
160	3.40	1.77	35.41
170	3.34	1.92	38.61
180	3.29	2.07	41.81
190	3.24	2.22	45.01
200	3.21	2.38	48.21
300	2.99	3.90	80.21
400	2.88	5.42	112.21
500	2.81	6.95	144.22
600	2.76	8.47	176.22
700	2.72	9.99	208.22
800	2.69	11.52	240.22
900	2.66	13.04	272.22
1,000	2.63	14.57	304.22
1,100	2.61	16.09	336.22
1,200	2.59	17.61	368.22
1,300	2.57	19.14	400.22
1,400	2.55	20.66	432.22
1,500	2.54	22.19	464.22
1,600	2.52	23.71	496.22
1,700	2.51	25.23	528.22
1,800	2.50	26.76	560.22
1,900	2.49	28.28	592.22
2,000	2.47	29.80	624.22
2,100	2.46	31.33	656.22
2,200	2.45	32.85	688.22
2,300	2.44	34.38	720.22
2,400	2.44	35.90	752.22
2,500	2.43	37.42	784.22
2,600	2.42	38.95	816.22
2,700	2.41	40.47	848.22
2,800	2.40	41.99	880.22
2,900	2.40	43.52	912.22
3,000	2.39	45.04	944.22
3,100	2.38	46.57	976.23
3,200	2.38	48.00	1008.23
3,300	2.35	48.00	1040.23
3,400	2.33	48.00	1072.23
3,500	2.30	48.00	1104.23
3,600	2.28	48.00	1136.23
3,700	2.26	48.00	1168.23
3,800	2.24	48.00	1200.23
3,900	2.22	48.00	1232.23
4,000	2.20	48.00	1264.23

PETER BEST PAPER ILLUSTRATIVE EXAMPLE - SINGLE TURBINE - Assumes Heights in Table 2 are meters above ground

Plume Averaged Vertical Velocities: **"*Aviation Safety and Buoyant Plumes*," Peter Best, et. al.**

Ambient Conditions:

Ambient Potential Temp θ_a	288	Kelvins	59	°F	Assume neutral conditions (dθ/dz=0)

Plume Exit Conditions:

Stack Height h_s	13.77	meters	45.2	feet	
Stack Diameter D	0.51	meters	1.7	feet	
Stack Velocity V_{exit}	59.22	m/s	194.3	ft/sec	
Volumetric Flow	12	cu.m/sec	25,427	ACFM	$\pi V_{exit}D^2/4$
Stack Potential Temp θ_s	751	Kelvins	891.9	°F	Back-Calc'd from Buoyancy Flux
Initial Stack Buoyancy Flux F_o	23	m^4/s^3			$gV_{exit}D^2(1-\theta_a/\theta_s)/4$ = Vol.Flow(g/π)(1-θ_a/θ_s) Sect.2/¶1
Plume Buoyancy Flux F	N/A	m^4/s^3			$\lambda^2 gVa^2(1-\theta_a/\theta_p)$ for a,V,θ_p at plume height (not used here)

Constants:

Gravity g	9.81	m/s^2
λ	1.11	
	0.3048	meters/feet

Conditions at End (Top) of Jet Phase:

Height above Stack z	3.188	meters*	10.5	feet*	6.25D, meters*=meters above stack top	Sect.3/¶1
Height above Ground z+h_s	16.956	meters	55.6	feet	h_s + 6.25D	"
Vertical Velocity V_{plume}	29.610	m/s	97.15	ft/sec	$0.5V_{exit}$ $V_{exit}/2$	"
Plume Top-Hat Diameter 2a	1.020	meters	3.3	feet	2D Conservation of momentum	"

Spillane Methodology - Analytical Solutions for Calm Conditions for Plume Heights above Jet Phase

Plume Top-Hat Radius a	**Solutions in Table Below**				0.16(z-z_v), or linear increase with height	Sect.2/Eq.6
Virtual Source Height z_v	1.213	meters*	4.0	feet*	$6.25D[1-(\theta_a/\theta_s)^{1/2}]$, meters*=meters above stack top	Sect.2/Eq.6
Height above Ground z_v+h_s	14.981	meters	49.1	feet	where $(\theta_a/\theta_s)^{1/2} = (\theta_a/\theta_s)^{1/2}$= 0.619478578	

Method(1): Simplified Plume-averaged Vertical Velocity V' - Assumes Product Va constant above jet phase such that $V_{plume}(2a) = V_{exit}D$

Vertical Velocity V'	**Solutions in Table Below**				$V_{exit}D/2a'$ (conservation of buoyancy)	Sect.3&4

Method(2): Plume-averaged Vertical Velocity V given by Analytical Solution in Paper where Product Va given by equations below:

Vertical Velocity V	**Solutions in Table Below**				$\{(Va)_a^3 + 0.12F_o[(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)} / a$	Sect.2.1(6)
Product $(Va)_o$	9.355	m^2/s			$V_{exit}D/2(\theta_a/\theta_s)^{1/2}$	

Table of plume Top-Hat Diameters (2a) and Plume-averaged Vertical Velocities for both Method(1) (assuming conservation of buoyancy & gaussian distribution of vertical velocities) and Method (2) (based on Peter Best's paper's Analytical Solution) starting at end of jet phase:

from 100 meters above ground in increments of 50.0 meters

Height above stack top, meters*	Ht above Ground = meters	h_{plume}+h_s feet	D_{plume}=2a= 2*0.16(z-z_v)	Vert.Vel (m/s) Method(1) V_{plume}= V_{exit}*D/2a	Method(2) $\{(Va)_a^3+0.12F_o[(z-z_v)^2$ $-(6.25D-z_v)^2]\}^{1/3}$ / a
End of jet phase at 6.25D = 3.188 meters*	***16.956***	***55.6***	***1.020***		***29.61***
86.232 meters*	**100.000**	328.1	27.206	1.11	**2.03**
136.232 meters*	150.000	492.1	43.206	0.70	1.72
186.232 meters*	**200.000**	656.2	59.206	0.51	**1.55**
236.232 meters*	250.000	820.2	75.206	0.40	1.43
286.232 meters*	**300.000**	984.3	91.206	0.33	**1.34**
336.232 meters*	350.000	1148.3	107.206	0.28	1.27
386.232 meters*	400.000	1312.3	123.206	0.25	1.21
436.232 meters*	450.000	1476.4	139.206	0.22	1.16
486.232 meters*	**500.000**	1640.4	155.206	0.19	**1.12**
536.232 meters*	550.000	1804.5	171.206	0.18	1.08
586.232 meters*	600.000	1968.5	187.206	0.16	1.05
636.232 meters*	650.000	2132.5	203.206	0.15	1.02
686.232 meters*	**700.000**	2296.6	219.206	0.14	**1.00**
736.232 meters*	750.000	2460.6	235.206	0.13	0.98
786.232 meters*	800.000	2624.7	251.206	0.12	0.95
836.232 meters*	850.000	2788.7	267.206	0.11	0.93
886.232 meters*	900.000	2952.8	283.206	0.11	0.92
936.232 meters*	950.000	3116.8	299.206	0.10	0.90
986.232 meters*	**1000.000**	3280.8	315.206	0.10	**0.88**
1036.232 meters*	1050.000	3444.9	331.206	0.09	0.87
1086.232 meters*	1100.000	3608.9	347.206	0.09	0.86
1136.232 meters*	1150.000	3773.0	363.206	0.08	0.84
1186.232 meters*	1200.000	3937.0	379.206	0.08	0.83
1236.232 meters*	1250.000	4101.0	395.206	0.08	0.82

4.520 meters*	18.288	60.0	1.058	28.54	17.82
7.568 meters*	21.336	70.0	2.034	14.85	9.57
10.616 meters*	24.384	80.0	3.009	10.04	6.77
13.664 meters*	27.432	90.0	3.984	7.58	5.39
13.969 meters*	27.737	91.0	4.082	7.40	5.30
14.274 meters*	28.042	92.0	4.180	7.23	5.20
14.579 meters*	28.347	93.0	4.277	7.06	5.11
14.884 meters*	28.652	94.0	4.375	6.90	5.03
15.188 meters*	28.956	95.0	4.472	6.75	4.95
15.493 meters*	29.261	96.0	4.570	6.61	4.87
15.798 meters*	29.566	97.0	4.667	6.47	4.80
16.103 meters*	29.871	98.0	4.765	6.34	4.73
16.408 meters*	30.176	99.0	4.862	6.21	4.66
16.712 meters*	30.480	100.0	4.960	6.09	4.59
17.017 meters*	30.785	101.0	5.057	5.97	4.53
17.322 meters*	31.090	102.0	5.155	5.86	4.47
17.627 meters*	31.395	103.0	5.252	5.75	4.42
17.932 meters*	31.700	104.0	5.350	5.65	4.36
18.236 meters*	32.004	105.0	5.448	5.54	4.31
18.541 meters*	32.309	106.0	5.545	5.45	4.26
18.846 meters*	32.614	107.0	5.643	5.35	4.21
19.151 meters*	32.919	108.0	5.740	5.26	4.16
19.456 meters*	33.224	109.0	5.838	5.17	4.12
19.760 meters*	33.528	110.0	5.935	5.09	4.08
22.808 meters*	36.576	120.0	6.911	4.37	3.71
23.113 meters*	36.881	121.0	7.008	4.31	3.68
23.418 meters*	37.186	122.0	7.106	4.25	3.65
23.723 meters*	37.491	123.0	7.203	4.19	3.62
24.028 meters*	37.796	124.0	7.301	4.14	3.60
24.332 meters*	38.100	125.0	7.398	4.08	3.57
25.856 meters*	39.624	130.0	7.886	3.83	3.44

ft	m/s	merged cells
60	17.82	1.00
70	9.57	1.00
80	6.77	1.00
90	5.39	1.00
91	5.30	1.00
92	5.20	1.00
93	5.11	1.00
94	5.03	1.00
95	4.95	1.00
96	4.87	1.00
97	4.80	1.00
98	4.73	1.00
99	4.66	1.00
100	4.59	1.00
101	4.53	1.00
102	4.47	1.00
103	4.42	1.00
104	4.36	1.00
105	4.31	1.00
106	4.26	1.00
107	4.21	1.00
108	4.16	1.00
109	4.12	1.00
110	4.08	1.01
120	3.85	1.16
121	3.83	1.17
122	3.81	1.19
123	3.80	1.21
124	3.78	1.22
125	3.76	1.24
130	3.69	1.31

Stack Distances (ft)	Number of Stacks
21	48
6.4008	

28.905 meters*	42.673	140.0	8.861	3.41	3.24
31.953 meters*	45.721	150.0	9.837	3.07	3.07
47.193 meters*	60.961	200.0	14.714	2.05	2.56
77.673 meters*	91.441	300.0	24.467	1.23	2.11
108.153 meters*	121.921	400.0	34.221	0.88	1.87
138.634 meters*	152.402	500.0	43.975	0.69	1.71
169.114 meters*	182.882	600.0	53.728	0.56	1.60
199.595 meters*	213.363	700.0	63.482	0.48	1.51
230.075 meters*	243.843	800.0	73.236	0.41	1.44
260.555 meters*	274.323	900.0	82.990	0.36	1.38
291.036 meters*	304.804	1000.0	92.743	0.33	1.33
321.516 meters*	335.284	1100.0	102.497	0.29	1.29
351.996 meters*	365.764	1200.0	112.251	0.27	1.25
382.477 meters*	396.245	1300.0	122.004	0.25	1.21
412.957 meters*	426.725	1400.0	131.758	0.23	1.18
443.438 meters*	457.206	1500.0	141.512	0.21	1.16
473.918 meters*	487.686	1600.0	151.266	0.20	1.13
504.398 meters*	518.166	1700.0	161.019	0.19	1.11
534.879 meters*	548.647	1800.0	170.773	0.18	1.09
565.359 meters*	579.127	1900.0	180.527	0.17	1.07
595.839 meters*	609.607	2000.0	190.280	0.16	1.05
626.320 meters*	640.088	2100.0	200.034	0.15	1.03
656.800 meters*	670.568	2200.0	209.788	0.14	1.01
687.281 meters*	701.049	2300.0	219.542	0.14	1.00
717.761 meters*	731.529	2400.0	229.295	0.13	0.98
748.241 meters*	762.009	2500.0	239.049	0.13	0.97
778.722 meters*	792.490	2600.0	248.803	0.12	0.96
809.202 meters*	822.970	2700.0	258.557	0.12	0.95
839.682 meters*	853.450	2800.0	268.310	0.11	0.93
870.163 meters*	883.931	2900.0	278.064	0.11	0.92
900.643 meters*	914.411	3000.0	287.818	0.10	0.91
931.124 meters*	944.891	3100.0	297.571	0.10	0.90
961.604 meters*	975.372	3200.0	307.325	0.10	0.89
992.084 meters*	1005.852	3300.0	317.079	0.10	0.88
1022.565 meters*	1036.333	3400.0	326.833	0.09	0.87
1053.045 meters*	1066.813	3500.0	336.586	0.09	0.87
1083.525 meters*	1097.293	3600.0	346.340	0.09	0.86
1114.006 meters*	1127.774	3700.0	356.094	0.08	0.85
1144.486 meters*	1158.254	3800.0	365.847	0.08	0.84
1174.966 meters*	1188.734	3900.0	375.601	0.08	0.83
1205.447 meters*	1219.215	4000.0	385.355	0.08	0.83

140	3.56	1.46
150	3.46	1.62
200	3.18	2.38
300	2.96	3.90
400	2.85	5.43
500	2.78	6.95
600	2.73	8.47
700	2.69	10.00
800	2.66	11.52
900	2.63	13.05
1,000	2.60	14.57
1,100	2.58	16.09
1,200	2.56	17.62
1,300	2.54	19.14
1,400	2.52	20.66
1,500	2.51	22.19
1,600	2.49	23.71
1,700	2.48	25.24
1,800	2.47	26.76
1,900	2.46	28.28
2,000	2.45	29.81
2,100	2.44	31.33
2,200	2.43	32.85
2,300	2.42	34.38
2,400	2.41	35.90
2,500	2.40	37.43
2,600	2.39	38.95
2,700	2.38	40.47
2,800	2.38	42.00
2,900	2.37	43.52
3,000	2.36	45.05
3,100	2.36	46.57
3,200	2.35	48.00
3,300	2.32	48.00
3,400	2.30	48.00
3,500	2.28	48.00
3,600	2.26	48.00
3,700	2.24	48.00
3,800	2.22	48.00
3,900	2.20	48.00
4,000	2.18	48.00

PETER BEST PAPER ILLUSTRATIVE EXAMPLE - SINGLE TURBINE - Assumes Heights in Table 2 are meters above ground

Plume Averaged Vertical Velocities: **"*Aviation Safety and Buoyant Plumes*," Peter Best, et. al.**

Ambient Conditions:

Ambient Potential Temp θ_a	298	Kelvins	76	°F	Assume neutral conditions (dθ/dz=0)
Plume Exit Conditions:					Gravity g 9.81 m/s^2
Stack Height h_s	13.77	meters	45.2	feet	λ 1.11
Stack Diameter D	0.51	meters	1.7	feet	0.3048 meters/feet
Stack Velocity V_{exit}	59.22	m/s	194.3	ft/sec	
Volumetric Flow	12	cu.m/sec	25,427	ACFM	$\pi V_{exit}D^2/4$ Sect.2/¶1
Stack Potential Temp θ_s	751	Kelvins	891.9	°F	Back-Calc'd from Buoyancy Flux
Initial Stack Buoyancy Flux F_o	23	m^4/s^3			$gV_{exit}D^2(1-\theta_a/\theta_s)/4$ = Vol.Flow(g/π)(1-θ_a/θ_s) Sect.2/¶1
Plume Buoyancy Flux F	N/A	m^4/s^3			$\lambda^2 gVa^2(1-\theta_a/\theta_a)$ for a,V,θ_a at plume height (not used here)

Conditions at End (Top) of Jet Phase:

Height above Stack z	3.188	meters*	10.5	feet*	6.25D, meters*=meters above stack top	Sect.3/¶1
Height above Ground z+h_s	16.956	meters	55.6	feet	h_s + 6.25D	"
Vertical Velocity V_{plume}	29.610	m/s	97.15	ft/sec	$0.5V_{exit}$ $V_{exit}/2$	"
Plume Top-Hat Diameter 2a	1.020	meters	3.3	feet	2D Conservation of momentum	"

Spillane Methodology - Analytical Solutions for Calm Conditions for Plume Heights above Jet Phase

Plume Top-Hat Radius a	**Solutions in Table Below**				0.16(z-z_v), or linear increase with height	Sect.2/Eq.6
Virtual Source Height z_v	1.181	meters*	3.9	feet*	$6.25D[1-(\theta_a/\theta_s)^{1/2}]$, meters*=meters above stack top	Sect.2/Eq.6
Height above Ground z_v+h_s	14.949	meters	49.0	feet	where $(\theta_a/\theta_s)^{1/2} = (\theta_a/\theta_s)^{1/2}$= 0.629548786	

Method(1): Simplified Plume-averaged Vertical Velocity V' - Assumes Product Va constant above jet phase such that $V_{plume}(2a) = V_{exit}D$

Vertical Velocity V'	**Solutions in Table Below**				$V_{exit}D/2a'$ (conservation of buoyancy)	Sect.3&4

Method(2): Plume-averaged Vertical Velocity V given by Analytical Solution in Paper where Product Va given by equations below:

Vertical Velocity V	**Solutions in Table Below**				$\{(Va)_o^3 + 0.12F_o[(z-z_o)^2 - (6.25D-z_o)^2]\}^{(1/3)}$ / a	Sect.2.1(6)
Product $(Va)_o$	9.507	m^2/s			$V_{exit}D/2(\theta_a/\theta_s)^{1/2}$	

Table of plume Top-Hat Diameters (2a) and Plume-averaged Vertical Velocities for both Method(1) (assuming conservation of buoyancy & gaussian distribution of vertical velocities) and Method (2) (based on Peter Best's paper's Analytical Solution) starting at end of jet phase:

from 100 meters above ground in increments of 50.0 meters

	Ht above Ground =	h_{plume}+h_s	D_{plume}=2a=	Vert.Vel (m/s) Method(1) V_{plume}=	Method(2) $\{(Va)_o^3+0.12F_o[(z-z_o)^2$
Height above stack top, meters*	meters	feet	2*0.16(z-z_o)	V_{exit}*D/2a	$-(6.25D-z_o)^2]\}^{1/3}$ / a
End of jet phase at 6.25D = 3.188 meters*	***16.956***	***55.6***	***1.020***		***29.61***
86.232 meters*	**100.000**	328.1	27.216	1.11	**2.02**
136.232 meters*	150.000	492.1	43.216	0.70	1.71
186.232 meters*	**200.000**	656.2	59.216	0.51	**1.54**
236.232 meters*	250.000	820.2	75.216	0.40	1.42
286.232 meters*	**300.000**	984.3	91.216	0.33	**1.33**
336.232 meters*	350.000	1148.3	107.216	0.28	1.26
386.232 meters*	400.000	1312.3	123.216	0.25	1.20
436.232 meters*	450.000	1476.4	139.216	0.22	1.15
486.232 meters*	**500.000**	1640.4	155.216	0.19	**1.11**
536.232 meters*	550.000	1804.5	171.216	0.18	1.08
586.232 meters*	600.000	1968.5	187.216	0.16	1.05
636.232 meters*	650.000	2132.5	203.216	0.15	1.02
686.232 meters*	**700.000**	2296.6	219.216	0.14	**0.99**
736.232 meters*	750.000	2460.6	235.216	0.13	0.97
786.232 meters*	800.000	2624.7	251.216	0.12	0.95
836.232 meters*	850.000	2788.7	267.216	0.11	0.93
886.232 meters*	900.000	2952.8	283.216	0.11	0.91
936.232 meters*	950.000	3116.8	299.216	0.10	0.89
986.232 meters*	**1000.000**	3280.8	315.216	0.10	**0.88**
1036.232 meters*	1050.000	3444.9	331.216	0.09	0.86
1086.232 meters*	1100.000	3608.9	347.216	0.09	0.85
1136.232 meters*	1150.000	3773.0	363.216	0.08	0.84
1186.232 meters*	1200.000	3937.0	379.216	0.08	0.83
1236.232 meters*	1250.000	4101.0	395.216	0.08	0.81

4.520 meters*	18.288	60.0	1.069	28.26	17.93
7.568 meters*	21.336	70.0	2.044	14.78	9.65
10.616 meters*	24.384	80.0	3.019	10.00	6.82
13.664 meters*	27.432	90.0	3.995	7.56	5.43
13.969 meters*	27.737	91.0	4.092	7.38	5.33
14.274 meters*	28.042	92.0	4.190	7.21	5.23
14.579 meters*	28.347	93.0	4.287	7.04	5.14
14.884 meters*	28.652	94.0	4.385	6.89	5.06
15.188 meters*	28.956	95.0	4.482	6.74	4.97
15.493 meters*	29.261	96.0	4.580	6.59	4.90
15.798 meters*	29.566	97.0	4.677	6.46	4.82
16.103 meters*	29.871	98.0	4.775	6.33	4.75
16.408 meters*	30.176	99.0	4.873	6.20	4.68
16.712 meters*	30.480	100.0	4.970	6.08	4.61
17.017 meters*	30.785	101.0	5.068	5.96	4.55
17.322 meters*	31.090	102.0	5.165	5.85	4.49
17.627 meters*	31.395	103.0	5.263	5.74	4.43
17.932 meters*	31.700	104.0	5.360	5.63	4.38
18.236 meters*	32.004	105.0	5.458	5.53	4.33
18.541 meters*	32.309	106.0	5.555	5.44	4.27
18.846 meters*	32.614	107.0	5.653	5.34	4.22
19.151 meters*	32.919	108.0	5.750	5.25	4.18
19.456 meters*	33.224	109.0	5.848	5.16	4.13
19.760 meters*	33.528	110.0	5.945	5.08	4.09
22.808 meters*	36.576	120.0	6.921	4.36	3.72
23.113 meters*	36.881	121.0	7.018	4.30	3.69
23.418 meters*	37.186	122.0	7.116	4.24	3.66
23.723 meters*	37.491	123.0	7.213	4.19	3.63

ft	m/s	merged cells
60	17.93	1.00
70	9.65	1.00
80	6.82	1.00
90	5.43	1.00
91	5.33	1.00
92	5.23	1.00
93	5.14	1.00
94	5.06	1.00
95	4.97	1.00
96	4.90	1.00
97	4.82	1.00
98	4.75	1.00
99	4.68	1.00
100	4.61	1.00
101	4.55	1.00
102	4.49	1.00
103	4.43	1.00
104	4.38	1.00
105	4.33	1.00
106	4.27	1.00
107	4.22	1.00
108	4.18	1.00
109	4.13	1.00
110	4.10	1.01
120	3.86	1.16
121	3.84	1.18
122	3.82	1.19
123	3.80	1.21

Stack Distances (ft)	Number of Stacks
21	48

24.028 meters*	37.796	124.0	7.311	4.13	3.60
24.332 meters*	38.100	125.0	7.409	4.08	3.57
47.193 meters*	60.961	200.0	14.724	2.05	2.55
77.673 meters*	91.441	300.0	24.478	1.23	2.10
108.153 meters*	121.921	400.0	34.231	0.88	1.86
138.634 meters*	152.402	500.0	43.985	0.69	1.70
169.114 meters*	182.882	600.0	53.739	0.56	1.59
199.595 meters*	213.363	700.0	63.492	0.48	1.50
230.075 meters*	243.843	800.0	73.246	0.41	1.43
260.555 meters*	274.323	900.0	83.000	0.36	1.37
291.036 meters*	304.804	1000.0	92.754	0.33	1.32
321.516 meters*	335.284	1100.0	102.507	0.29	1.28
351.996 meters*	365.764	1200.0	112.261	0.27	1.24
382.477 meters*	396.245	1300.0	122.015	0.25	1.21
412.957 meters*	426.725	1400.0	131.768	0.23	1.18
443.438 meters*	457.206	1500.0	141.522	0.21	1.15
473.918 meters*	487.686	1600.0	151.276	0.20	1.12
504.398 meters*	518.166	1700.0	161.030	0.19	1.10
534.879 meters*	548.647	1800.0	170.783	0.18	1.08
565.359 meters*	579.127	1900.0	180.537	0.17	1.06
595.839 meters*	609.607	2000.0	190.291	0.16	1.04
626.320 meters*	640.088	2100.0	200.044	0.15	1.02
656.800 meters*	670.568	2200.0	209.798	0.14	1.01
687.281 meters*	701.049	2300.0	219.552	0.14	0.99
717.761 meters*	731.529	2400.0	229.306	0.13	0.98
748.241 meters*	762.009	2500.0	239.059	0.13	0.96
778.722 meters*	792.490	2600.0	248.813	0.12	0.95
809.202 meters*	822.970	2700.0	258.567	0.12	0.94
839.682 meters*	853.450	2800.0	268.321	0.11	0.93
870.163 meters*	883.931	2900.0	278.074	0.11	0.92
900.643 meters*	914.411	3000.0	287.828	0.10	0.91
931.124 meters*	944.891	3100.0	297.582	0.10	0.90
961.604 meters*	975.372	3200.0	307.335	0.10	0.89
992.084 meters*	1005.852	3300.0	317.089	0.10	0.88
1022.565 meters*	1036.333	3400.0	326.843	0.09	0.87
1053.045 meters*	1066.813	3500.0	336.597	0.09	0.86
1083.525 meters*	1097.293	3600.0	346.350	0.09	0.85
1114.006 meters*	1127.774	3700.0	356.104	0.08	0.84
1144.486 meters*	1158.254	3800.0	365.858	0.08	0.84
1174.966 meters*	1188.734	3900.0	375.611	0.08	0.83
1205.447 meters*	1219.215	4000.0	385.365	0.08	0.82

124	3.78	1.22
125	3.77	1.24
200	3.17	2.38
300	2.95	3.90
400	2.84	5.43
500	2.77	6.95
600	2.71	8.48
700	2.67	10.00
800	2.64	11.52
900	2.61	13.05
1,000	2.58	14.57
1,100	2.56	16.09
1,200	2.54	17.62
1,300	2.52	19.14
1,400	2.51	20.67
1,500	2.49	22.19
1,600	2.48	23.71
1,700	2.46	25.24
1,800	2.45	26.76
1,900	2.44	28.28
2,000	2.43	29.81
2,100	2.42	31.33
2,200	2.41	32.86
2,300	2.40	34.38
2,400	2.39	35.90
2,500	2.38	37.43
2,600	2.38	38.95
2,700	2.37	40.48
2,800	2.36	42.00
2,900	2.35	43.52
3,000	2.35	45.05
3,100	2.34	46.57
3,200	2.33	48.00
3,300	2.31	48.00
3,400	2.29	48.00
3,500	2.26	48.00
3,600	2.24	48.00
3,700	2.22	48.00
3,800	2.20	48.00
3,900	2.18	48.00
4,000	2.16	48.00

PETER BEST PAPER ILLUSTRATIVE EXAMPLE - SINGLE TURBINE - Assumes Heights in Table 2 are meters above ground

Plume Averaged Vertical Velocities: **"*Aviation Safety and Buoyant Plumes*," Peter Best, et. al.**

Ambient Conditions:					Constants:	
Ambient Potential Temp θ_a	309	Kelvins	96	°F	Assume neutral conditions (dθ/dz=0)	
Plume Exit Conditions:					Gravity g 9.81 m/s^2	
Stack Height h_s	13.77	meters	45.2	feet	λ 1.11	
Stack Diameter D	0.51	meters	1.7	feet	0.3048 meters/feet	
Stack Velocity V_{exit}	59.22	m/s	194.3	ft/sec		
Volumetric Flow	12	cu.m/sec	25,427	ACFM	$\pi V_{exit}D^2/4$	Sect.2/¶1
Stack Potential Temp θ_s	751	Kelvins	891.9	°F	Back-Calc'd from Buoyancy Flux	
Initial Stack Buoyancy Flux F_o	22	m^4/s^3			$gV_{exit}D^2(1-\theta_a/\theta_s)/4$ = Vol.Flow$(g/\pi)(1-\theta_a/\theta_s)$	Sect.2/¶1
Plume Buoyancy Flux F	N/A	m^4/s^3			$\lambda^2 gVa^2(1-\theta_a/\theta_a)$ for a,V,θ_a at plume height (not used here)	
Conditions at End (Top) of Jet Phase:						
Height above Stack z	3.188	meters*	10.5	feet*	6.25D, meters*=meters above stack top	Sect.3/¶1
Height above Ground z+h_s	16.956	meters	55.6	feet	h_s + 6.25D	"
Vertical Velocity V_{plume}	29.610	m/s	97.15	ft/sec	$0.5V_{exit}$ $V_{exit}/2$	"
Plume Top-Hat Diameter 2a	1.020	meters	3.3	feet	2D Conservation of momentum	"

Spillane Methodology - Analytical Solutions for Calm Conditions for Plume Heights above Jet Phase

Plume Top-Hat Radius a	**Solutions in Table Below**				0.16(z-z_v), or linear increase with height	Sect.2/Eq.6
Virtual Source Height z_v	1.144	meters*	3.8	feet*	$6.25D[1-(\theta_a/\theta_s)^{1/2}]$, meters*=meters above stack top	Sect.2/Eq.6
Height above Ground z_v+h_s	14.912	meters	48.9	feet	where $(\theta_a/\theta_s)^{1/2} = (\theta_a/\theta_s)^{1/2}$= 0.641193636	

Method(1): Simplified Plume-averaged Vertical Velocity V' - Assumes Product Va constant above jet phase such that $V_{plume}(2a) = V_{exit}D$

Vertical Velocity V'	**Solutions in Table Below**				$V_{exit}D/2a'$ (conservation of buoyancy)	Sect.3&4

Method(2): Plume-averaged Vertical Velocity V given by Analytical Solution in Paper where Product Va given by equations below:

Vertical Velocity V	**Solutions in Table Below**				$\{(Va)_o^3 + 0.12F_o[(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)}$ / a	Sect.2.1(6)
Product $(Va)_o$	9.683	m^2/s			$V_{exit}D/2(\theta_a/\theta_s)^{1/2}$	

Table of plume Top-Hat Diameters (2a) and Plume-averaged Vertical Velocities for both Method(1) (assuming conservation of buoyancy & gaussian distribution of vertical velocities) and Method (2) (based on Peter Best's paper's Analytical Solution) starting at end of jet phase:

from 100 meters above ground in increments of 50.0 meters

				Vert.Vel (m/s)	
				Method(1)	Method(2)
	Ht above Ground =	h_{plume}+h_s	D_{plume}=2a=	V_{plume}=	$\{(Va)_o^3+0.12F_o[(z-z_v)^2$
Height above stack top, meters*	meters	feet	2*0.16(z-z_v)	V_{exit}*D/2a	$-(6.25D-z_v)^2]\}^{1/3}$ / a
End of jet phase at 6.25D = 3.188 meters*	***16.956***	***55.6***	***1.020***		***29.61***
86.232 meters*	**100.000**	328.1	27.228	1.11	**2.00**
136.232 meters*	150.000	492.1	43.228	0.70	1.70
186.232 meters*	**200.000**	656.2	59.228	0.51	**1.53**
236.232 meters*	250.000	820.2	75.228	0.40	1.41
286.232 meters*	**300.000**	984.3	91.228	0.33	**1.32**
336.232 meters*	350.000	1148.3	107.228	0.28	1.25
386.232 meters*	400.000	1312.3	123.228	0.25	1.19
436.232 meters*	450.000	1476.4	139.228	0.22	1.14
486.232 meters*	**500.000**	1640.4	155.228	0.19	**1.10**
536.232 meters*	550.000	1804.5	171.228	0.18	1.07
586.232 meters*	600.000	1968.5	187.228	0.16	1.04
636.232 meters*	650.000	2132.5	203.228	0.15	1.01
686.232 meters*	**700.000**	2296.6	219.228	0.14	**0.98**
736.232 meters*	750.000	2460.6	235.228	0.13	0.96
786.232 meters*	800.000	2624.7	251.228	0.12	0.94
836.232 meters*	850.000	2788.7	267.228	0.11	0.92
886.232 meters*	900.000	2952.8	283.228	0.11	0.90
936.232 meters*	950.000	3116.8	299.228	0.10	0.89
986.232 meters*	**1000.000**	3280.8	315.228	0.10	**0.87**
1036.232 meters*	1050.000	3444.9	331.228	0.09	0.86
1086.232 meters*	1100.000	3608.9	347.228	0.09	0.84
1136.232 meters*	1150.000	3773.0	363.228	0.08	0.83
1186.232 meters*	1200.000	3937.0	379.228	0.08	0.82
1236.232 meters*	1250.000	4101.0	395.228	0.08	0.81

4.520 meters*	18.288	60.0	1.080	27.95	18.05
7.568 meters*	21.336	70.0	2.056	14.69	9.75
10.616 meters*	24.384	80.0	3.031	9.96	6.89
13.664 meters*	27.432	90.0	4.007	7.54	5.47
13.969 meters*	27.737	91.0	4.104	7.36	5.37
14.274 meters*	28.042	92.0	4.202	7.19	5.27
14.579 meters*	28.347	93.0	4.299	7.03	5.18
14.884 meters*	28.652	94.0	4.397	6.87	5.09
15.188 meters*	28.956	95.0	4.494	6.72	5.01
15.493 meters*	29.261	96.0	4.592	6.58	4.93
15.798 meters*	29.566	97.0	4.689	6.44	4.85
16.103 meters*	29.871	98.0	4.787	6.31	4.78
16.408 meters*	30.176	99.0	4.884	6.18	4.71
16.712 meters*	30.480	100.0	4.982	6.06	4.64
17.017 meters*	30.785	101.0	5.080	5.95	4.58
17.322 meters*	31.090	102.0	5.177	5.83	4.51
17.627 meters*	31.395	103.0	5.275	5.73	4.46
17.932 meters*	31.700	104.0	5.372	5.62	4.40
18.236 meters*	32.004	105.0	5.470	5.52	4.34
18.541 meters*	32.309	106.0	5.567	5.43	4.29
18.846 meters*	32.614	107.0	5.665	5.33	4.24
19.151 meters*	32.919	108.0	5.762	5.24	4.19
19.456 meters*	33.224	109.0	5.860	5.15	4.15
19.760 meters*	33.528	110.0	5.957	5.07	4.10
22.808 meters*	36.576	120.0	6.933	4.36	3.72
23.113 meters*	36.881	121.0	7.030	4.30	3.69
23.418 meters*	37.186	122.0	7.128	4.24	3.66
23.723 meters*	37.491	123.0	7.225	4.18	3.63

ft	m/s	merged cells
60	18.05	1.00
70	9.75	1.00
80	6.89	1.00
90	5.47	1.00
91	5.37	1.00
92	5.27	1.00
93	5.18	1.00
94	5.09	1.00
95	5.01	1.00
96	4.93	1.00
97	4.85	1.00
98	4.78	1.00
99	4.71	1.00
100	4.64	1.00
101	4.58	1.00
102	4.51	1.00
103	4.46	1.00
104	4.40	1.00
105	4.34	1.00
106	4.29	1.00
107	4.24	1.00
108	4.19	1.00
109	4.15	1.00
110	4.11	1.01
120	3.87	1.16
121	3.85	1.18
122	3.83	1.19
123	3.81	1.21

Stack Distances (ft)	Number of Stacks
21	48

24.028 meters*	37.796	124.0	7.323	4.12	3.60
24.332 meters*	38.100	125.0	7.420	4.07	3.57
47.193 meters*	60.961	200.0	14.736	2.05	2.54
77.673 meters*	91.441	300.0	24.489	1.23	2.08
108.153 meters*	121.921	400.0	34.243	0.88	1.84
138.634 meters*	152.402	500.0	43.997	0.69	1.69
169.114 meters*	182.882	600.0	53.751	0.56	1.58
199.595 meters*	213.363	700.0	63.504	0.48	1.49
230.075 meters*	243.843	800.0	73.258	0.41	1.42
260.555 meters*	274.323	900.0	83.012	0.36	1.36
291.036 meters*	304.804	1000.0	92.765	0.33	1.31
321.516 meters*	335.284	1100.0	102.519	0.29	1.27
351.996 meters*	365.764	1200.0	112.273	0.27	1.23
382.477 meters*	396.245	1300.0	122.027	0.25	1.20
412.957 meters*	426.725	1400.0	131.780	0.23	1.17
443.438 meters*	457.206	1500.0	141.534	0.21	1.14
473.918 meters*	487.686	1600.0	151.288	0.20	1.11
504.398 meters*	518.166	1700.0	161.041	0.19	1.09
534.879 meters*	548.647	1800.0	170.795	0.18	1.07
565.359 meters*	579.127	1900.0	180.549	0.17	1.05
595.839 meters*	609.607	2000.0	190.303	0.16	1.03
626.320 meters*	640.088	2100.0	200.056	0.15	1.01
656.800 meters*	670.568	2200.0	209.810	0.14	1.00
687.281 meters*	701.049	2300.0	219.564	0.14	0.98
717.761 meters*	731.529	2400.0	229.318	0.13	0.97
748.241 meters*	762.009	2500.0	239.071	0.13	0.96
778.722 meters*	792.490	2600.0	248.825	0.12	0.94
809.202 meters*	822.970	2700.0	258.579	0.12	0.93
839.682 meters*	853.450	2800.0	268.332	0.11	0.92
870.163 meters*	883.931	2900.0	278.086	0.11	0.91
900.643 meters*	914.411	3000.0	287.840	0.10	0.90
931.124 meters*	944.891	3100.0	297.594	0.10	0.89
961.604 meters*	975.372	3200.0	307.347	0.10	0.88
992.084 meters*	1005.852	3300.0	317.101	0.10	0.87
1022.565 meters*	1036.333	3400.0	326.855	0.09	0.86
1053.045 meters*	1066.813	3500.0	336.608	0.09	0.85
1083.525 meters*	1097.293	3600.0	346.362	0.09	0.84
1114.006 meters*	1127.774	3700.0	356.116	0.08	0.84
1144.486 meters*	1158.254	3800.0	365.870	0.08	0.83
1174.966 meters*	1188.734	3900.0	375.623	0.08	0.82
1205.447 meters*	1219.215	4000.0	385.377	0.08	0.81

124	3.79	1.22
125	3.77	1.24
200	3.16	2.38
300	2.92	3.91
400	2.81	5.43
500	2.74	6.95
600	2.69	8.48
700	2.65	10.00
800	2.62	11.52
900	2.59	13.05
1,000	2.56	14.57
1,100	2.54	16.10
1,200	2.52	17.62
1,300	2.50	19.14
1,400	2.49	20.67
1,500	2.47	22.19
1,600	2.46	23.72
1,700	2.44	25.24
1,800	2.43	26.76
1,900	2.42	28.29
2,000	2.41	29.81
2,100	2.40	31.33
2,200	2.39	32.86
2,300	2.38	34.38
2,400	2.37	35.91
2,500	2.36	37.43
2,600	2.36	38.95
2,700	2.35	40.48
2,800	2.34	42.00
2,900	2.33	43.52
3,000	2.33	45.05
3,100	2.32	46.57
3,200	2.31	48.00
3,300	2.29	48.00
3,400	2.27	48.00
3,500	2.24	48.00
3,600	2.22	48.00
3,700	2.20	48.00
3,800	2.18	48.00
3,900	2.16	48.00
4,000	2.15	48.00

PETER BEST PAPER ILLUSTRATIVE EXAMPLE - SINGLE TURBINE - Assumes Heights in Table 2 are meters above ground

Plume Averaged Vertical Velocities: **"*Aviation Safety and Buoyant Plumes*," Peter Best, et. al.**

Ambient Conditions:					Constants:		
Ambient Potential Temp θ_a	272	Kelvins	30	°F	Assume neutral conditions (dθ/dz=0)		
Plume Exit Conditions:					Gravity g	9.81	m/s^2
Stack Height h_s	36.58	meters	120.0	feet	λ	1.11	
Stack Diameter D	0.71	meters	2.3	feet		0.3048	meters/feet
Stack Velocity V_{exit}	9.40	m/s	30.8	ft/sec			
Volumetric Flow	4	cu.m/sec	8,476	ACFM	$\pi V_{exit}D^2/4$		Sect.2/¶1
Stack Potential Temp θ_s	312	Kelvins	101.5	°F	Back-Calc'd from Buoyancy Flux		
Initial Stack Buoyancy Flux F_o	1	m^4/s^3			$gV_{exit}D^2(1-\theta_a/\theta_s)/4$ = Vol.Flow(g/π)(1-θ_a/θ_s)		Sect.2/¶1
Plume Buoyancy Flux F	N/A	m^4/s^3			$\lambda^2 gVa^2(1-\theta_a/\theta_p)$ for a,V,θ_p at plume height (not used here)		

Conditions at End (Top) of Jet Phase:

Height above Stack z	4.445	meters*	14.6	feet*	6.25D, meters*=meters above stack top		Sect.3/¶1
Height above Ground z+h_s	41.021	meters	134.6	feet	h_s + 6.25D		"
Vertical Velocity V_{plume}	4.699	m/s	15.42	ft/sec	$0.5V_{exit}$	$V_{exit}/2$	"
Plume Top-Hat Diameter 2a	1.422	meters	4.7	feet	2D	Conservation of momentum	"

Spillane Methodology - Analytical Solutions for Calm Conditions for Plume Heights above Jet Phase

Plume Top-Hat Radius a	**Solutions in Table Below**				0.16(z-z_v), or linear increase with height	Sect.2/Eq.6
Virtual Source Height z_v	0.293	meters*	1.0	feet*	$6.25D[1-(\theta_a/\theta_s)^{1/2}]$, meters*=meters above stack top	Sect.2/Eq.6
Height above Ground z_v+h_s	36.869	meters	121.0	feet	where $(\theta_a/\theta_s)^{1/2} = (\theta_a/\theta_s)^{1/2}$= 0.93412399	

Method(1): Simplified Plume-averaged Vertical Velocity V' - Assumes Product Va constant above jet phase such that $V_{plume}(2a) = V_{exit}D$

Vertical Velocity V'	**Solutions in Table Below**				$V_{exit}D/2a'$ (conservation of buoyancy)	Sect.3&4

Method(2): Plume-averaged Vertical Velocity V given by Analytical Solution in Paper where Product Va given by equations below:

Vertical Velocity V	**Solutions in Table Below**				$\{(Va)_n^3 + 0.12F_o [(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)}$ / a	Sect.2.1(6)
Product $(Va)_o$	3.122	m^2/s			$V_{exit}D/2(\theta_a/\theta_s)^{1/2}$	

Table of plume Top-Hat Diameters (2a) and Plume-averaged Vertical Velocities for both Method(1) (assuming conservation of buoyancy & gaussian distribution of vertical velocities) and Method (2) (based on Peter Best's paper's Analytical Solution) starting at end of jet phase:

from 100 meters above ground in increments of 50.0 meters

				Vert.Vel (m/s)	
				Method(1)	Method(2)
	Ht above Ground =	h_{plume}+h_s	D_{plume}=2a=	V_{plume}=	$\{(Va)_n^3+0.12F_o[(z-z_v)^2$
Height above stack top, meters*	meters	feet	2*0.16(z-z_v)	V_{exit}*D/2a	$-(6.25D-z_v)^2]\}^{1/3}$ / a
End of jet phase at 6.25D = 4.445 meters*	***41.021***	***134.6***	***1.422***		***4.70***
63.424 meters*	**100.000**	328.1	20.202	0.33	**0.89**
113.424 meters*	150.000	492.1	36.202	0.18	0.73
163.424 meters*	**200.000**	656.2	52.202	0.13	**0.64**
213.424 meters*	250.000	820.2	68.202	0.10	0.59
263.424 meters*	**300.000**	984.3	84.202	0.08	**0.55**
313.424 meters*	350.000	1148.3	100.202	0.07	0.52
363.424 meters*	400.000	1312.3	116.202	0.06	0.49
413.424 meters*	450.000	1476.4	132.202	0.05	0.47
463.424 meters*	**500.000**	1640.4	148.202	0.05	**0.45**
513.424 meters*	550.000	1804.5	164.202	0.04	0.44
563.424 meters*	600.000	1968.5	180.202	0.04	0.43
613.424 meters*	650.000	2132.5	196.202	0.03	0.41
663.424 meters*	**700.000**	2296.6	212.202	0.03	**0.40**
713.424 meters*	750.000	2460.6	228.202	0.03	0.39
763.424 meters*	800.000	2624.7	244.202	0.03	0.38
813.424 meters*	850.000	2788.7	260.202	0.03	0.38
863.424 meters*	900.000	2952.8	276.202	0.02	0.37
913.424 meters*	950.000	3116.8	292.202	0.02	0.36
963.424 meters*	**1000.000**	3280.8	308.202	0.02	**0.36**
1013.424 meters*	1050.000	3444.9	324.202	0.02	0.35
1063.424 meters*	1100.000	3608.9	340.202	0.02	0.34
1113.424 meters*	1150.000	3773.0	356.202	0.02	0.34
1163.424 meters*	1200.000	3937.0	372.202	0.02	0.33
1213.424 meters*	1250.000	4101.0	388.202	0.02	0.33

0.000 meters*	36.576	120.0	-0.094	-71.33	-64.32
0.305 meters*	36.881	121.0	0.004	1743.32	1571.79
0.610 meters*	37.186	122.0	0.101	65.94	59.46
0.914 meters*	37.491	123.0	0.199	33.60	30.32
1.219 meters*	37.796	124.0	0.296	22.55	20.37
1.524 meters*	38.100	125.0	0.394	16.97	15.35
1.829 meters*	38.405	126.0	0.492	13.60	12.32
2.134 meters*	38.710	127.0	0.589	11.35	10.31
2.438 meters*	39.015	128.0	0.687	9.73	8.86
2.743 meters*	39.320	129.0	0.784	8.52	7.78
3.048 meters*	39.624	130.0	0.882	7.58	6.95
3.353 meters*	39.929	131.0	0.979	6.83	6.28
3.658 meters*	40.234	132.0	1.077	6.21	5.73
3.962 meters*	40.539	133.0	1.174	5.69	5.28
4.267 meters*	40.844	134.0	1.272	5.26	4.90
4.572 meters*	41.149	135.0	1.369	4.88	4.57
4.877 meters*	41.453	136.0	1.467	4.56	4.29
5.182 meters*	41.758	137.0	1.564	4.27	4.04
5.486 meters*	42.063	138.0	1.662	4.02	3.83
5.791 meters*	42.368	139.0	1.760	3.80	3.64
6.096 meters*	42.673	140.0	1.857	3.60	3.47
6.401 meters*	42.977	141.0	1.955	3.42	3.32
6.706 meters*	43.282	142.0	2.052	3.26	3.18
7.010 meters*	43.587	143.0	2.150	3.11	3.05
7.315 meters*	43.892	144.0	2.247	2.97	2.94
7.620 meters*	44.197	145.0	2.345	2.85	2.84
7.925 meters*	44.501	146.0	2.442	2.74	2.75
8.230 meters*	44.806	147.0	2.540	2.63	2.66
8.535 meters*	45.111	148.0	2.637	2.53	2.58
8.839 meters*	45.416	149.0	2.735	2.44	2.51
9.144 meters*	45.721	150.0	2.832	2.36	2.44

Stack Distances (ft) Number of Stacks

2 72

ft	m/s	merged cells	Plume Diamter Feet
120	-64.53	1.01	-0.31
121	1635.75	1.17	0.01
122	63.89	1.33	0.33
123	33.52	1.49	0.65
124	23.09	1.65	0.97
125	17.81	1.81	1.29
126	14.60	1.97	1.61
127	12.45	2.13	1.93
128	10.91	2.29	2.25
129	9.74	2.45	2.57
130	8.83	2.61	2.89
131	8.10	2.77	3.21
132	7.50	2.93	3.53
133	7.00	3.09	3.85
134	6.57	3.25	4.17
135	6.21	3.41	4.49
136	5.90	3.57	4.81
137	5.62	3.73	5.13
138	5.38	3.89	5.45
139	5.16	4.05	5.77
140	4.97	4.21	6.09
141	4.79	4.37	6.41
142	4.64	4.53	6.73
143	4.50	4.69	7.05
144	4.37	4.85	7.37
145	4.25	5.01	7.69
146	4.14	5.17	8.01
147	4.04	5.33	8.33
148	3.95	5.49	8.65
149	3.87	5.65	8.97
150	3.79	5.81	9.29

24.384 meters*	60.961	200.0	7.709	0.87	1.32
54.865 meters*	91.441	300.0	17.463	0.38	0.94
85.345 meters*	121.921	400.0	27.217	0.25	0.81
115.825 meters*	152.402	500.0	36.970	0.18	0.72
146.306 meters*	182.882	600.0	46.724	0.14	0.67
176.786 meters*	213.363	700.0	56.478	0.12	0.63
207.267 meters*	243.843	800.0	66.232	0.10	0.60
237.747 meters*	274.323	900.0	75.985	0.09	0.57
268.227 meters*	304.804	1000.0	85.739	0.08	0.55
298.708 meters*	335.284	1100.0	95.493	0.07	0.53
329.188 meters*	365.764	1200.0	105.246	0.06	0.51
359.668 meters*	396.245	1300.0	115.000	0.06	0.49
390.149 meters*	426.725	1400.0	124.754	0.05	0.48
420.629 meters*	457.206	1500.0	134.508	0.05	0.47
451.109 meters*	487.686	1600.0	144.261	0.05	0.46
481.590 meters*	518.166	1700.0	154.015	0.04	0.45
512.070 meters*	548.647	1800.0	163.769	0.04	0.44
542.551 meters*	579.127	1900.0	173.522	0.04	0.43
573.031 meters*	609.607	2000.0	183.276	0.04	0.42
603.511 meters*	640.088	2100.0	193.030	0.03	0.42
633.992 meters*	670.568	2200.0	202.784	0.03	0.41
664.472 meters*	701.049	2300.0	212.537	0.03	0.40
694.952 meters*	731.529	2400.0	222.291	0.03	0.40
725.433 meters*	762.009	2500.0	232.045	0.03	0.39
755.913 meters*	792.490	2600.0	241.799	0.03	0.39
786.394 meters*	822.970	2700.0	251.552	0.03	0.38
816.874 meters*	853.450	2800.0	261.306	0.03	0.38
847.354 meters*	883.931	2900.0	271.060	0.02	0.37
877.835 meters*	914.411	3000.0	280.813	0.02	0.37
908.315 meters*	944.891	3100.0	290.567	0.02	0.36
938.795 meters*	975.372	3200.0	300.321	0.02	0.36
969.276 meters*	1005.852	3300.0	310.075	0.02	0.36
999.756 meters*	1036.333	3400.0	319.828	0.02	0.35
1030.237 meters*	1066.813	3500.0	329.582	0.02	0.35
1060.717 meters*	1097.293	3600.0	339.336	0.02	0.34
1091.197 meters*	1127.774	3700.0	349.089	0.02	0.34
1121.678 meters*	1158.254	3800.0	358.843	0.02	0.34
1152.158 meters*	1188.734	3900.0	368.597	0.02	0.34
1182.638 meters*	1219.215	4000.0	378.351	0.02	0.33
1182.638 meters*	1219.215	4000.0	378.351	0.02	0.33
1182.638 meters*	1219.215	4000.0	378.351	0.02	0.33

200	2.54	13.81	25.29
300	2.20	29.81	57.29
400	2.10	45.81	89.29
500	2.03	61.81	121.29
600	1.95	72.00	153.29
700	1.83	72.00	185.29
800	1.73	72.00	217.30
900	1.66	72.00	249.30
1,000	1.59	72.00	281.30
1,100	1.53	72.00	313.30
1,200	1.49	72.00	345.30
1,300	1.44	72.00	377.30
1,400	1.40	72.00	409.30
1,500	1.37	72.00	441.30
1,600	1.34	72.00	473.30
1,700	1.31	72.00	505.30
1,800	1.28	72.00	537.30
1,900	1.26	72.00	569.30
2,000	1.23	72.00	601.30
2,100	1.21	72.00	633.30
2,200	1.19	72.00	665.30
2,300	1.17	72.00	697.30
2,400	1.16	72.00	729.30
2,500	1.14	72.00	761.30
2,600	1.13	72.00	793.30
2,700	1.11	72.00	825.30
2,800	1.10	72.00	857.30
2,900	1.08	72.00	889.30
3,000	1.07	72.00	921.30
3,100	1.06	72.00	953.30
3,200	1.05	72.00	985.30
3,300	1.04	72.00	1017.30
3,400	1.02	72.00	1049.31
3,500	1.01	72.00	1081.31
3,600	1.00	72.00	1113.31
3,700	1.00	72.00	1145.31
3,800	0.99	72.00	1177.31
3,900	0.98	72.00	1209.31
4,000	0.97	72.00	1241.31
4,000	0.97	72.00	1241.31
4,000	0.97	72.00	1241.31